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Thermal Performance Measurements of a 100 Percent Polyester MLI System for the Superconducting Super Collider; Part I: Instrumentation and Experimental Preparation (300 K - 80 K)*

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THERMAL PERFORMANCE MEASUREMENTS OF A 100 PERCENT POLYESTER MLI SYSTEM FOR THE SUPERCONDUCTING SUPER COLLIDER; PART I: INSTRUMENTATION AND EXPERIMENTAL PREPARATION (300K - 80K)

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ABSTRACT

Thermal performance measurements of a 100 percent polyester multilayer insulation (MLI) system for the Superconducting Super Collider (SSC) were conducted in a Heat Leak Test Facility (HLTF) under three experimental test arrangements. Each experiment measured the thermal performance of a 32-layer MLI blanket instrumented with twenty foil sensors to measure interstitial layer temperatures. Heat leak values and sensor temperatures were monitored during transient and steady state conditions under both design and degraded insulating vacuums. Heat leak values were measured using a heatmeter. MLI interstitial layer temperatures were measured using Cryogenic Linear Temperature Sensors (CLTS). Platinum resistors monitored system temperatures. High vacuum was measured using ion gauges; degraded vacuum employed thermocouple gauges. A four-wire system monitored instrumentation sensors and calibration heaters. An on-line computerized data acquisition system recorded and processed data. This paper reports on the instrumentation and experimental preparation used in carrying out these measurements. In complement with this paper is an associate paper bearing the same title head, but with the title extension PART II: LABORATORY RESULTS (300K - 80K)[1].

OVERVIEW

The MLI system for the SSC must limit cryostat heat load from thermal radiation and residual gas conduction to levels specified by the SSC design requirements[2]. Equivalent in importance with the thermal performance of the system are the logistics involved in fabricating and installing the MLI system on the 10,000 magnets of the SSC accelerator. The MLI system is installed as blankets on the 4.5K cold mass and the 20K and 80K thermal shields. Each MLI blanket consists of as many as 32 reflective and 31 spacer layers and may be as large as 17.2 meters long by 1.8 meters wide.

The SSC magnet development program has led to innovative MLI fabrication and installation techniques that address the handling needs of the MLI system[3]. The fabrication technique employs parallel sewn seams to secure the layers together. Inherent to the MLI system is layer-to-layer registration, controlled layer density, and dimensional stability in a package that is easy to handle and install.

Thermal performance measurements of the MLI system using two sewn seam geometries were made under laboratory conditions. Measurements made of a polyester system without sewn seams provided direct performance comparisons to other systems previously measured[4]. Measurements with different seam geometries revealed the effects of varying sewn seam geometry on system performance. In addition, the interlayer temperature distribution for the different seam geometries was studied under varying system conditions, i.e., boundary temperatures and system pressures.

HEAT LEAK TEST FACILITY

The MLI performance measurements were conducted in a Heat Leak Test Facility. The HLTF has previously been described in detail[5] and is therefore briefly discussed here. Figure 1 shows the HLTF geometry as configured for MLI heat leak measurements to 80K.

<u>Temperature Measurements</u> - In each test arrangement, the MLI blanket was installed around the sides and top of a cylindrical copper cold plate. The cold plate is 39.4 cm. in diameter and 30.5 cm. in height. Internal to the cold plate is a resistance heater employed to confirm the accuracy of the measurement method. The cold plate is cooled by conduction through the heatmeter[6].

Surrounding the MLI blanket is a cylindrical copper hot plate. The hot plate provides a variable-temperature warm boundary surface. Temperature of the hot plate is maintained by a cryogenic temperature controller using a platinum resistance temperature detector (RTD) feedback sensor. Spirally wrapped around the outer surface is a single 0.321 mm. diameter double Formvar-coated wire that serves as the hot plate heater. The outer surface of the cold plate and inner surface of the hot plate were painted with 3M ECP-2200 Solar Absorbing Coating to approximate a surface emissivity of 1.

Allen-Bradley carbon-composition resistors are employed in the HLTF to measure temperatures below 50K. Platinum RTD's are used to measure temperatures above 50K. Excitation currents of 10 uA and 100 uA are supplied to the resistors and RTD's respectively to provide maximum sensitivity without inducing self-heating errors. Thermal EMF errors are canceled by averaging readings made across each sensor under inverted current polarities.

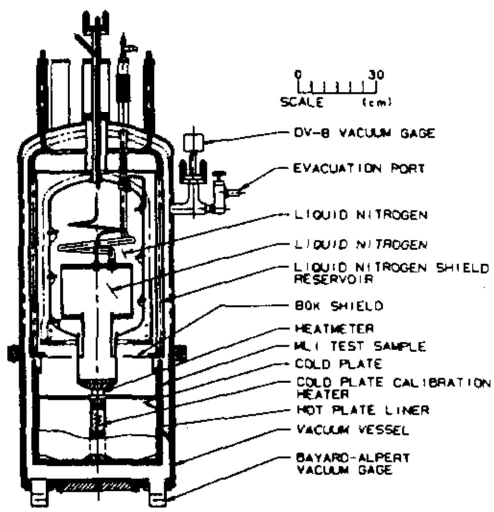

Fig. 1. Heat Leak Test Facility for MLI measurements.

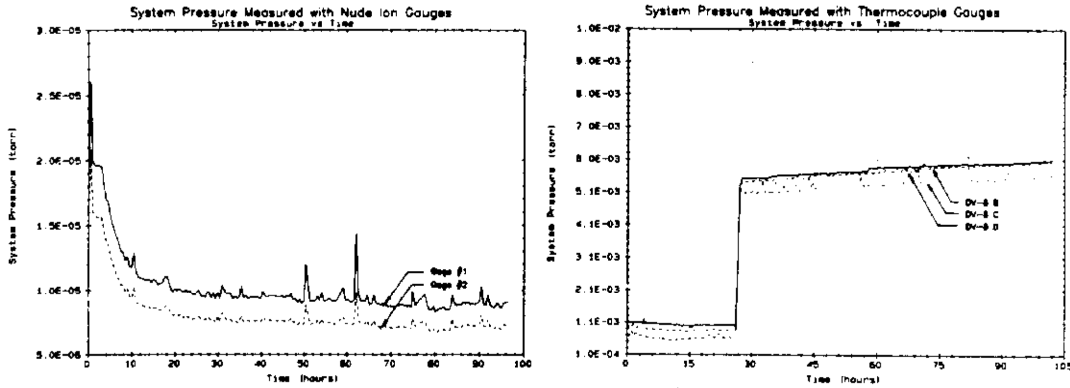

Fig. 2. System pressure measurements under good and degraded vacuum conditions.

Vacuum Measurements - Insulating vacuum in the HLTF is provided by a turbo-molecular pump through an isolation valve. Two Bayard-Alpert nude ion gauges sense the pressure below 1 micron. It has been shown that the sensitivity of Bayard-Alpert gauges may vary by a factor of 2.5 when the filament-to-grid spacing varies from 0.5 to 6 mm.[7]. The principal cause of error is filament sag. Prior to installation into the HLTF, both gauges are physically inspected and the grid-to-filament spacing adjusted to be identical.

Hastings DV-8 thermocouple gauges are used to measure the system pressure between 1 micron and 10 microns. Pressure above 10 microns is measured using Hastings DV-6 thermocouple gauges. Errors induced by different cable lengths have been corrected through an in-house calibration using Hastings reference tubes[8].

Vacuum measurements are made using redundant systems that operate independent of one another. Vacuum gauges at different locations are used to monitor system pressure to equilibrium. The result of careful hardware calibration is illustrated in Fig. 2 through close agreement of system pressure data obtained with independent pressure measurement systems.

Heat Leak Measurements - Heat leak in the HLTF is measured by means of a heatmeter. The heatmeter employs a thermally resistive reference section that is sandwiched between thermally conductive ends. For measurements to 80K, a pair of platinum RTD's sense the temperature across the reference section. Calibration curves were generated that equate the temperature drop across the reference section to a value of heat flow generated by an electrical calibration heater. The calibration curves are stored in the computer for on-line calculations of heat leak. Near 80K the sensitivity of the heatmeter has been determined to be 10 mW[6].

System Accuracy - A computer-controlled data acquisition system continuously monitors the thermometers through a four-wire lead system. Also monitored on-line are voltage outputs from the ion gauges, thermocouple gauges, and liquid level controllers. In addition, the excitation currents to the thermometers are continuously measured as voltages across precision 1K resistors with the same scanning unit used for the measurements. The data acquisition and analysis software for HLTF measurements was developed in-house to meet the specific requirements of the measurements.

Voltage measurements are accurate to six decimal places. Temperatures below 50K are measured to better than +/- 0.5K; temperatures above 50K to better than +/- 0.1K. The measurement methods used are capable of measuring only the degree of vacuum, and not the absolute pressure of the system. Therefore, the only claim to accuracy is based on the close agreement of pressure readings through tracking by redundant sensors.

INSTRUMENTATION METHODS

Component Instrumentation - Measurement preparation began with the fabrication and instrumentation of the hardware components. Platinum RTD's were employed for their sensitivity and linearity in the temperature range above 50K. All thermometers employ a four-wire system, with twisted pairs of current and voltage leads exiting each thermometer.

Four 15 cm. lengths of 0.127 mm. diameter copper wire insulated with Heavy Armored Polythermaleze are twisted in pairs and are soldered to each thermometer. The wires are thermally bonded to the component surface with GE7031 varnish[9]. It has been observed on several occasions that the solvents in GE7031 have dissolved various types of electrical insulations. Therefore, to avoid ground shorts a single piece of camera lens tissue is placed between the sensor lead wires and the component surface. The lens tissue is completely saturated with GE7031 as the lead-wires are laid in place. After the varnish has air-dried, the sensor is covered with 3M aluminum tape to limit the effects of thermal radiation on the temperature measurements.

Thermometers in all installations are mounted on the inner, or colder, surface of the component to be measured. As thermal energy flows from hot to cold, heat influencing the sensor must first pass through the component. Erroneous temperature measurements caused by warm surface thermal radiation influences on the sensor are eliminated.

Spliced to the copper leads are 0.203 mm. diameter manganin lead-wires with PVC insulation over Formvar coating. The manganin leads continue through the facility to pin-connectors located on the vessel exterior. Care must be taken when routing lead-wires to assure that no lead-wires are thermally-anchored to a surface of rapidly changing temperature. Thermal EMF's generated by the changing temperature will produce significant errors when making sensitive measurements.

Blanket Instrumentation - Careful consideration was given to the selection of instrumentation for measuring the interstitial temperatures of MLI layers without influencing the temperature of the layers by resistive heating of the thermometer or through solid conduction of the lead-wires.

The inherent characteristics of the Cryogenic Linear Temperature Sensor (CLTS)[10] made it an ideal choice to sense the individual layer temperatures. The CLTS has a high temperature response because of its small mass and thin composition (7.9 mm. x 10.9 mm. x 0.1 mm. thick). In addition, the CLTS exhibits high repeatability and stability while possessing a linear temperature / resistance relationship from 338 K to 4.2 K. With a 5-digit voltmeter on the 0.1K scale, temperature resolution of +/- 0.7 K has been reported[11]. Furthermore, CLTS's offer good thermal isolation from other sources of heat through thermally-isolated wire leads. Each CLTS was wired in a four-wire system and supplied with an excitation current of 10 uA.

Lead-wire metal alloy selection was based on the ability to limit lead-wire conduction to less than 10 percent of the total heat through the sensor area as a result of the expected heat flux through the blanket. From previous data it was determined that the heat flux from 300K to 80K through the MLI blanket would be approximately 110 uW/cm^2. Given the area of one CLTS to be approximately 1 cm^2, then the maximum conduction through the lead-wires should be limited to less than 11 uW.

Nylon-sleeved enamel-coated 0.051 mm. diameter Balco wire[12] was employed in 122 cm. long twisted pairs for sensor lead-wires. Manufacturer's information lists the alloy composition of Balco as 70% Ni and 30% Fe. As thermal conductivity information on Balco was unavailable, data on an alloy of similar composition was used to calculate the heat conduction through the lead-wires.

Contracid is an alloy comprised of 60% Ni, 15% Cr, 16% Fe, and 7% Mo. The integral of thermal conductivity between 300K and 80K for Contracid[13] is 20.94 W/cm. Using the solid heat conduction formula one calculates a conduction heat load of 3.48 uW per wire, or a total conductive heat load of 13.92 uW through four lead-wires to each CLTS. This would be for the worst-case condition, as most of the layers would be at a temperature below 300K. To further reduce lead-wire influences, the wires were anchored at 80K instead of 300K. This would remove heat from the warmer outer layers, with a decreasing influence as the layer temperatures became colder.

The CLTS's were fabricated as assemblies with the twisted lead-wires attached. After the lead-wires were soldered to the CLTS's, each assembly was cycled several times to 77K in a LN_2 bath. Four-wire resistance measurements recorded the resistance at both room temperature and 77K. A resistance verses temperature curve was generated and stored in a computer file for each assembly.

A total of twenty CLTS's were installed within each MLI test blanket. Fourteen of the sensors were placed in the body of the blanket, away from the seam area. The remaining six sensors were installed between sewn seams to understand the influence of seam geometry on the interlayer temperature distribution. Figure 3 illustrates the distribution and circumferential location of the sensors throughout the blanket layers. Defined are the layer numbers to which sensors were applied.

The CLTS's were bonded to the cold side of the selected layers with a thin coat of GE7031 varnish. The layers were held apart while the varnish air-dried to avoid bonding individual layers together. A single piece of aluminized Mylar tape was then placed over the sensor to serve as a thermal radiation shield. Approximately 30 cm. of lead-wire length extended beyond the blanket edge. The additional 92 cm. of lead-wire length was stored within the blanket layers. The lead-wires were soldered to terminals bonded to a 0.254 mm. thick G-11 band that was in point contact with the LN_2 reservoir. Twisted pairs of 0.203 mm. diameter manganin wires were soldered to the connecting ends of the terminals and were thermally anchored to the LN_2 reservoir before exiting the cryostat.

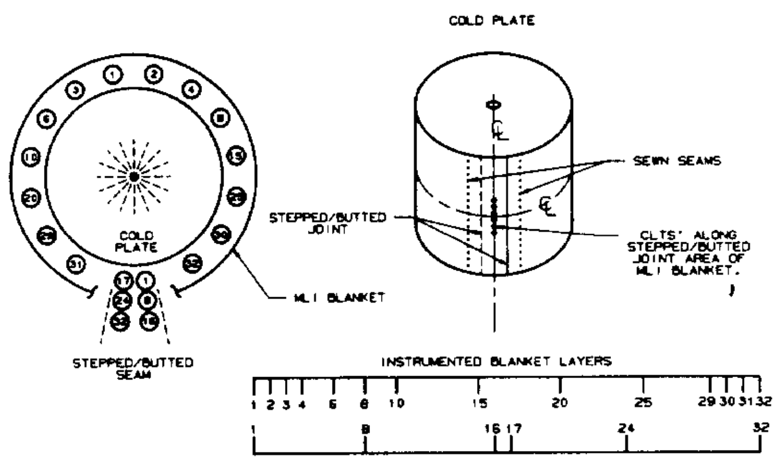

Fig. 3. Thermometer positioning in the MLI blanket.

MLI INSTALLATION IN THE HLTF

A detailed description of blanket fabrication for each MLI blanket test arrangement is presented in the associate paper[1]. Therefore, discussion here is limited to blanket installation on the cold plate.

For each MLI test arrangement the instrumented blanket was wrapped around the cylindrical portion of the cold plate. Sensors in the joint area were installed as the joint was closed. Each MLI installation was completed by placing alternate disks of reflective and spacer material on the top surface of the cold plate and connecting them to corresponding side blanket layers with minimal amounts of reflective tape.

PRELIMINARY MEASUREMENT RESULTS

Presented here are examples of measurement data obtained through the preparation methods discussed. An explanation of the data along with a comprehensive discussion of the results is included in Reference 1.

System equilibrium is defined in the HLTF as a time period > 8 hours in which the heat leak to 80K is steady to within +/- 5 mW with all system temperatures remaining constant to within 1%. Table 1 lists a sample data point in which steady-state has been obtained. The data is from the measurement of the taped joint / no seam MLI system.

Figure 4 illustrates the performance of the CLTS assemblies installed on the interstitial blanket layers. The graph shows the temperature distribution through the blanket at steady state with a warm boundary temperature of 300K. Evidence that individual layers are at uniform temperature is given by the fact that sensors near the joint report the same temperature as sensors on the same layer in the body of the blanket. Figure 3 shows the separation between the sensors in the body of the blanket and those near the joint. Recalling that each CLTS has its own calibration curve, the graph attests to the accuracy of the thermometry from unit to unit.

Figure 5 illustrates the performance of the interstitial blanket thermometers during the initial cooldown of the taped joint / no seam blanket installation. The small perturbation in the cooldown curve near 62 hours is caused by a system LN_2 fill. Note that the first layer against the cold plate is not at the same temperature as the cold plate as is often assumed, but is approximately 15K warmer.

Table 1. Taped joint / no seam MLI system in equilibrium

Log Time	Vacuum (Torr)	Heat Leak (W)	Cold Plate (K)	Hot Plate (K)	$k_{ap'nt}$ (uW/cmK)	Heat Flux (W/M^2)
22:16:32	3.22E-05	0.372	79.909	299.674	0.2999	0.744
23:16:45	3.15E-05	0.369	79.922	299.698	0.2977	0.738
00:16:39	3.11E-05	0.375	79.909	299.698	0.3021	0.750
01:16:39	3.07E-05	0.369	79.922	299.685	0.2977	0.738
02:16:28	3.03E-05	0.372	79.922	299.686	0.2999	0.744
03:16:46	3.00E-05	0.372	79.897	299.712	0.2999	0.744
04:16:29	2.97E-05	0.369	79.909	299.698	0.2977	0.738
05:16:44	2.93E-05	0.375	79.897	299.724	0.3021	0.750
06:16:34	2.92E-05	0.372	79.909	299.711	0.2999	0.744

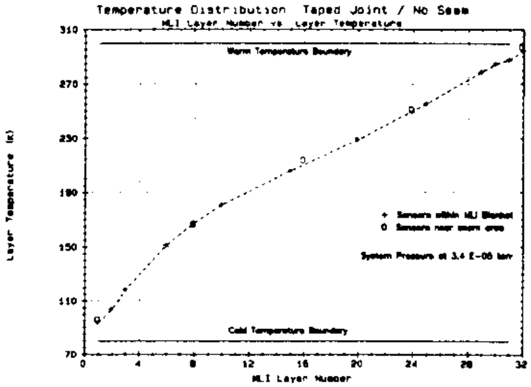

Fig. 4. Temperature distribution within the MLI blanket.

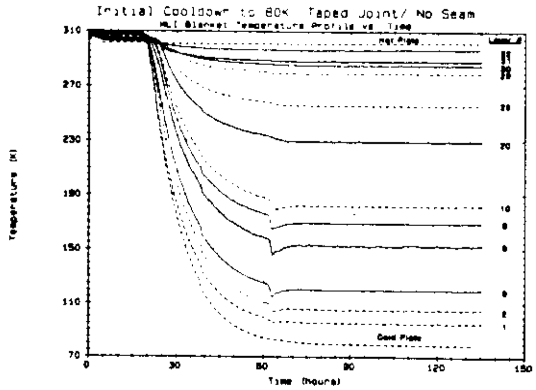

Fig. 5. Interstitial temperature profile during cooldown.

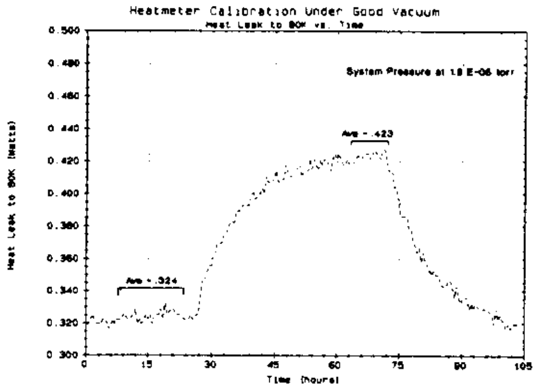

Fig. 6. Heatmeter calibration under good vacuum.

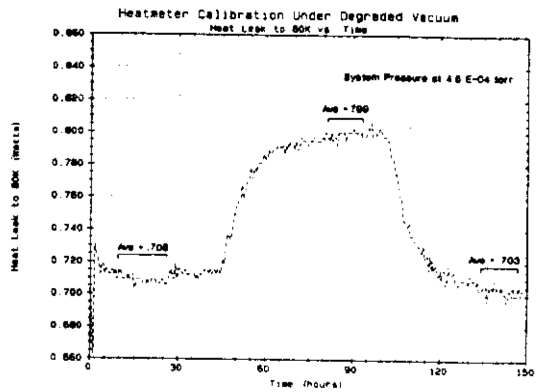

Fig. 7. Heatmeter calibration under degraded vacuum.

Critical to the precision of all measurements in the HLTF is the accuracy to which the heatmeter measures heat leak to 80K. Measurement accuracy is confirmed by applying electrical power to the cold plate calibration heater with the system at steady-state. Verification of heatmeter accuracy under high vacuum is illustrated in Fig. 6. Shown in Fig. 7 is the calibration of the heatmeter with a degraded vacuum of 4.0 E-4 Torr. Under both conditions, 100 mW of electrical power was applied to the cold plate calibration heater. Given the sensitivity of the heatmeter to be 10 mW, the calibration confirms the accuracy of the heat leak measurements under high vacuum. Under degraded vacuum the calibration assures that the heatmeter is not "shorted" by increased gas pressure in the system.

While the graphs confirm the sensitivity of the heatmeter, they also illustrate another critical point; long time periods can be required to reach steady-state in a cryogenic system.

CONCLUSIONS

The methods presented here have been successfully applied to measurements of a 100-percent polyester MLI system for the SSC. The warm and cold boundary temperatures were measured and controlled to values better than 0.1K. System pressure was monitored through independent measurement systems and provided redundant confirmation of pressure level. Heat leak values to 80K were measured to +/- 5 mW using a heatmeter. The on-line data acquisition system provided the capability of monitoring long equilibrium times, which proved necessary to achieve steady-state conditions within the system. The use of CLTS's to measure the interstitial temperature distribution within an MLI system proved effective as measurements were made on the system without influencing the heat flux measurements. Further discussion of the measurement results is presented in Reference 1.

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